APPENDIX 3-C

TUOLUMNE UTILITIES DISTRICT

3-C-1 Phoenix Lake Preservation and Restoration Plan - 30% Plan Submittal

3-C- 2 Phoenix Lake Preservation and Restoration Plan – Chapter 4 - Water Quality Monitoring & Improvement Plan

APPENDIX 3-C -1

TUOLUMNE UTILITIES DISTRICT

Phoenix Lake Preservation and Restoration Plan - 30% Plan Submittal

PHOENIX LAKE
PRESERVATION AND RESTORATION PLAN

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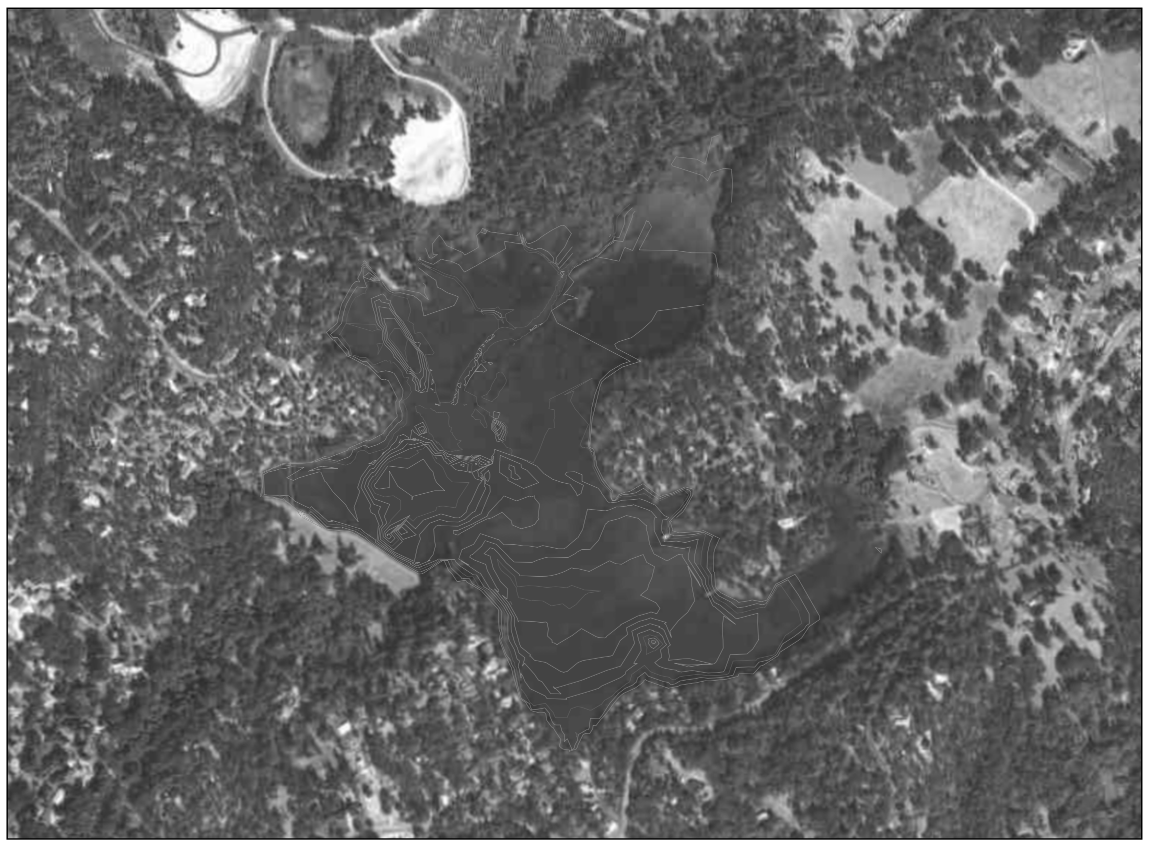

PROJECT MAP

VICINITY MAP

SHEET INDEX

LEGEND

EXISTING CONTOURS
PROPOSED CONTOURS
GRADING BREAKLINE
PROPERTY LINE

CONTACTS

TUOLUMNE UTILITIES DISTRICT	TED ALLEN, ASSOCIATE CIVIL ENGINEER	(209) 532-5536

TOPOGRAPHIC DATA REFERENCE CALIFORNIA STATE PLANE, ZONE 3, FEET.
VERTICAL DATUM IS NAVD88, FEET.

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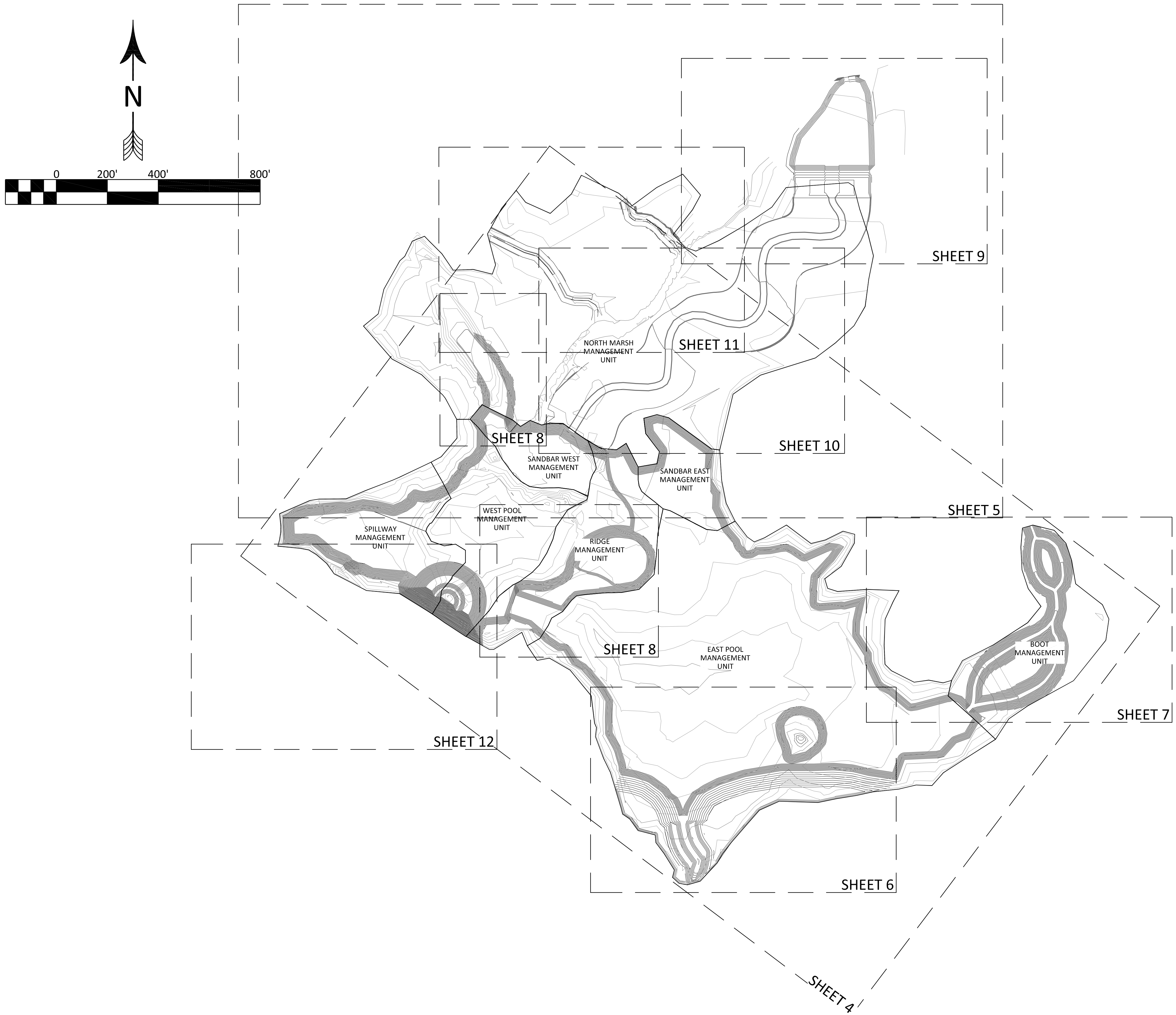
SONORA CALIFORNIA

PHOENIX LAKE PRESERVATION AND RESTORATION PLAN
COVER SHEET

FILE NAME Cover.dwg
JOB NUMBER 10-1019
DATE February, 2012
SHEET NO. 1 OF 13



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PHOENIX LAKE PRESERVATION AND RESTORATION PLAN
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FILE NAME
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JOB NUMBER
10-1019
DATE
February, 2012
SHEET NO.
2 OF 13

A B C D E

1 2 3 4

NOTES:
1. BATHYMETRIC AND TOPOGRAPHIC DATA OUTSIDE THE EXTENTS OF THE 2010 SURVEY WAS RECORDED IN A 2002 SURVEY EFFORT.
2. ALL SURVEY DATA REFERENCES THE CALIFORNIA STATE PLANE, ZONE 3 GEOGRAPHIC DATUM AND THE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88)

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PHOENIX LAKE PRESERVATION AND RESTORATION PLAN
EXISTING CONDITIONS

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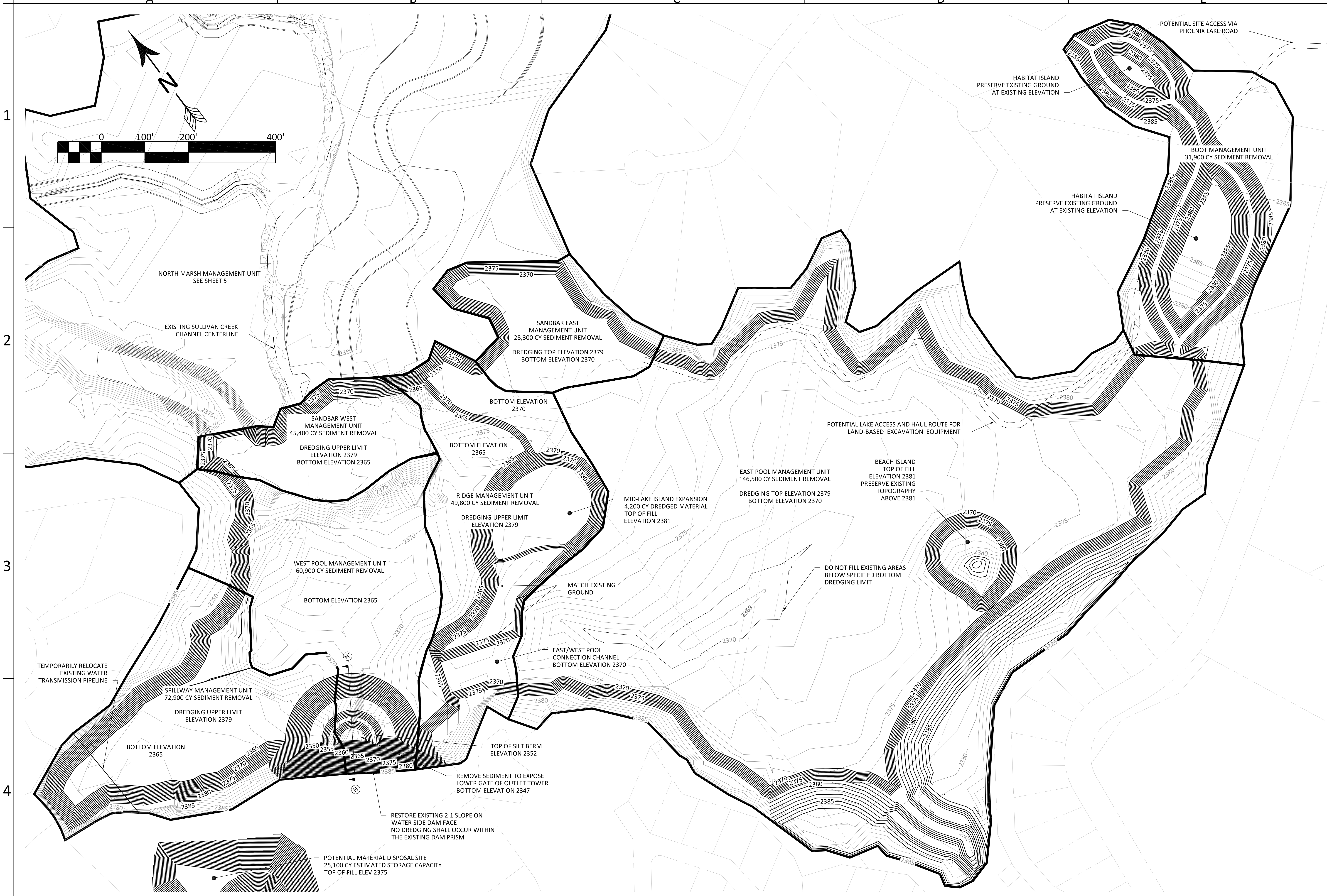
3 OF 13



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PHOENIX LAKE PRESERVATION AND RESTORATION PLAN

OVERALL LAKE DREDGING PLAN

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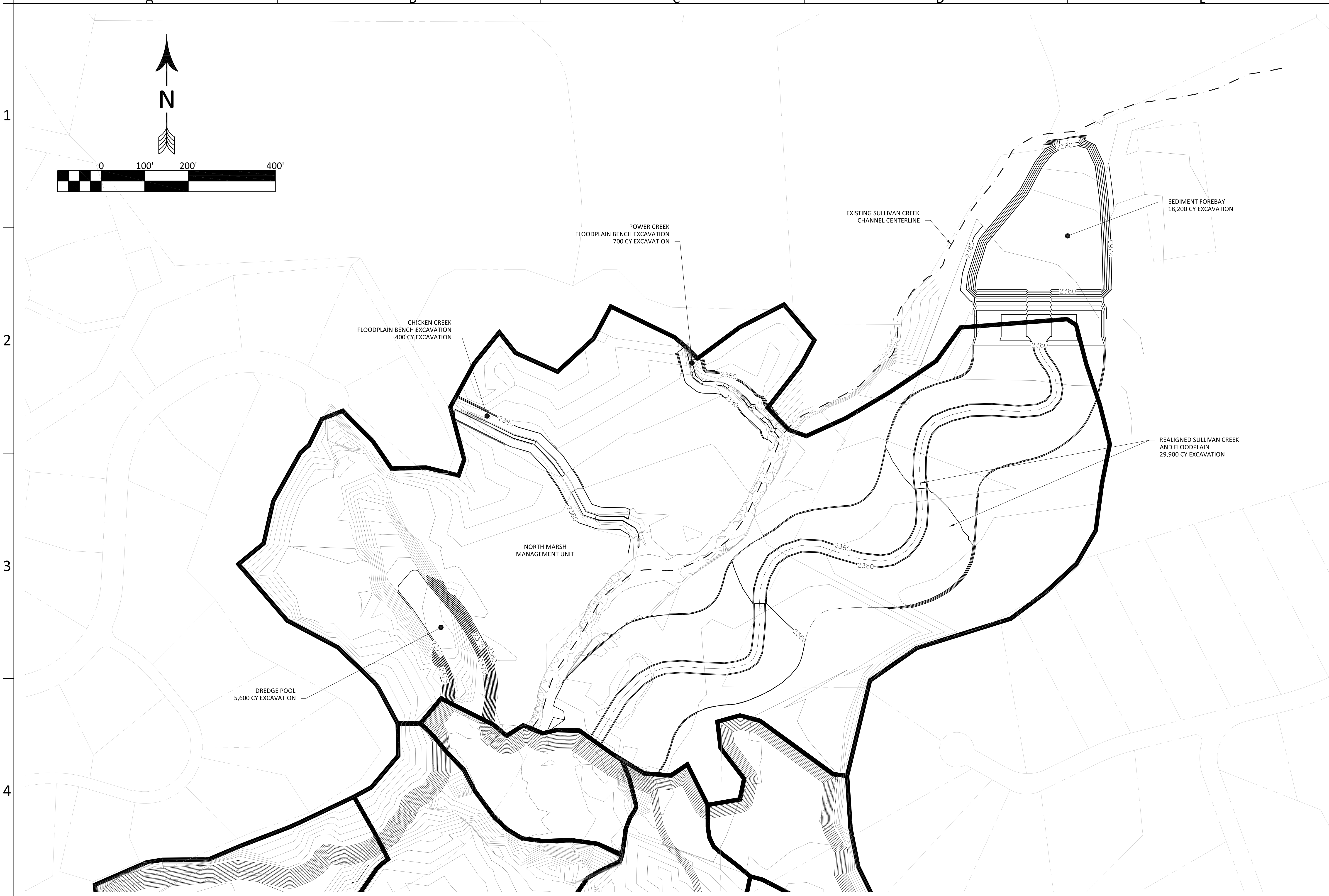
JOB NUMBER: 10-1019
DATE: February, 2012
SHEET NO. 4 OF 13



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PHOENIX LAKE PRESERVATION AND RESTORATION PLAN
OVERALL NORTH MARSH GRADING PLAN

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DATE
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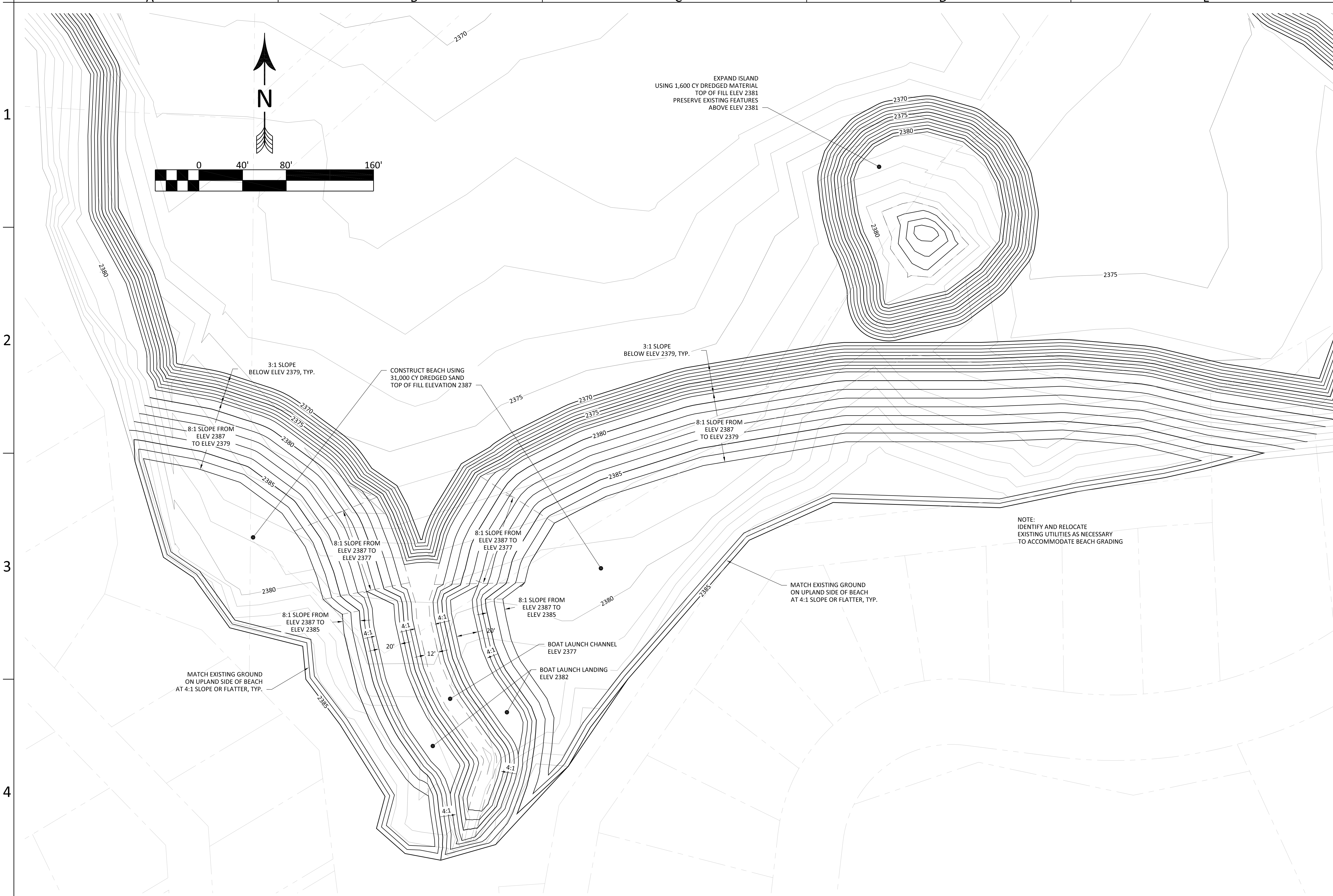
SHEET NO.
5 OF 13



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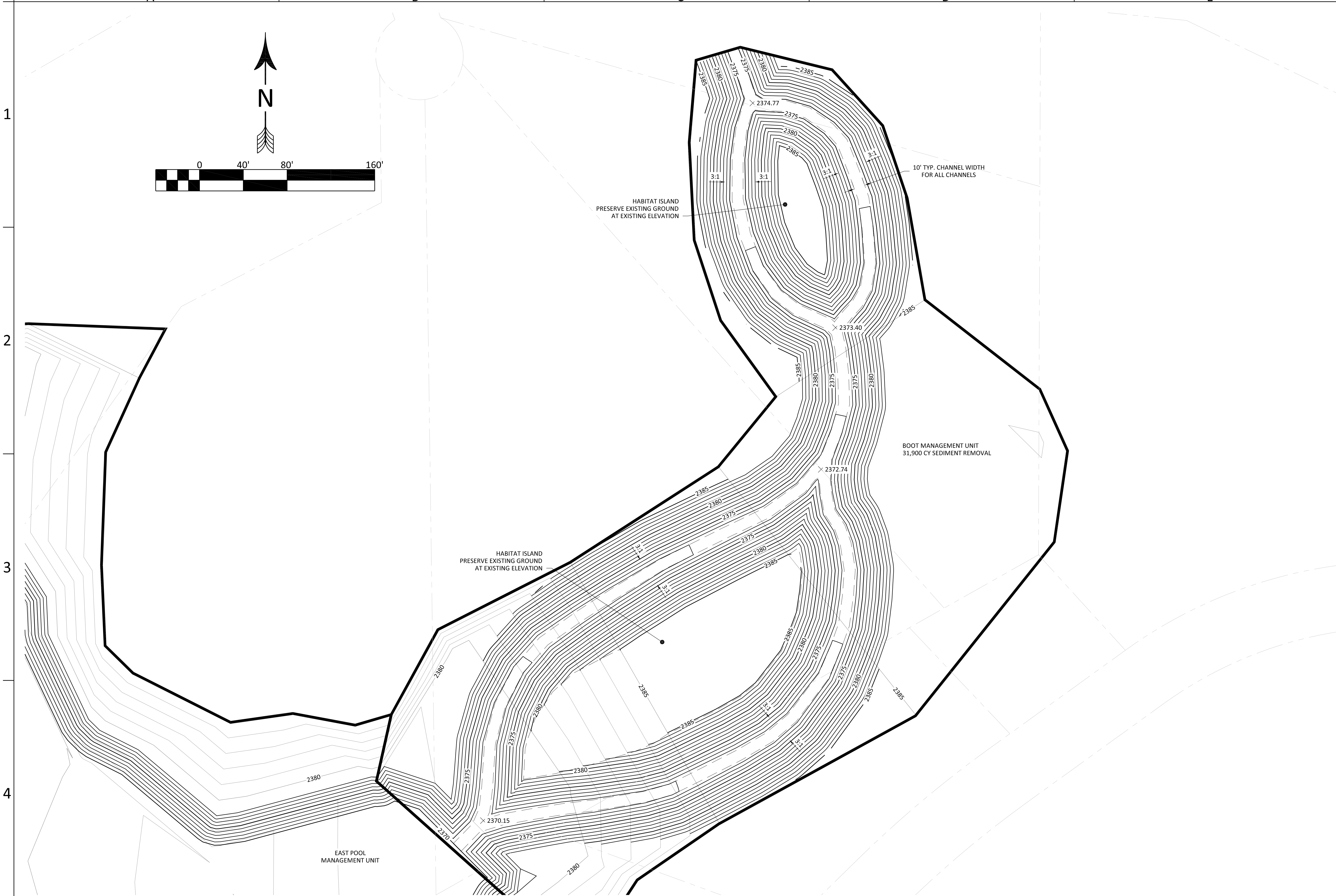
RESTORATION PLAN
BEACH GRADING PLAN

FILE NAME Beach.dwg
JOB NUMBER 10-1019
DATE February, 2012
SHEET NO. 6 OF 13



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PHOENIX LAKE PRESERVATION AND RESTORATION PLAN

BOOT MANAGEMENT UNIT GRADING PLAN

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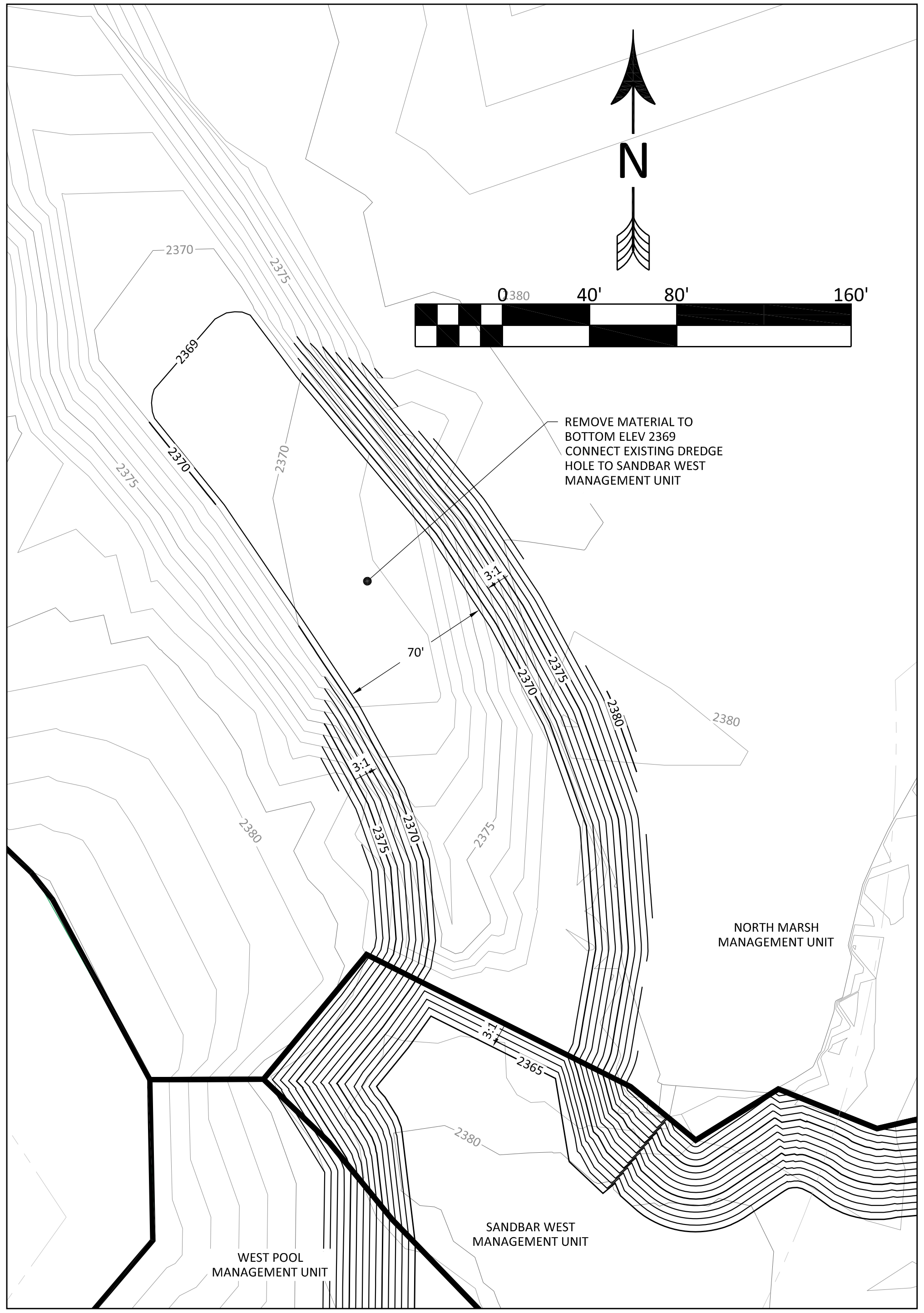
DATE
February, 2012

SHEET NO.
7 OF 13



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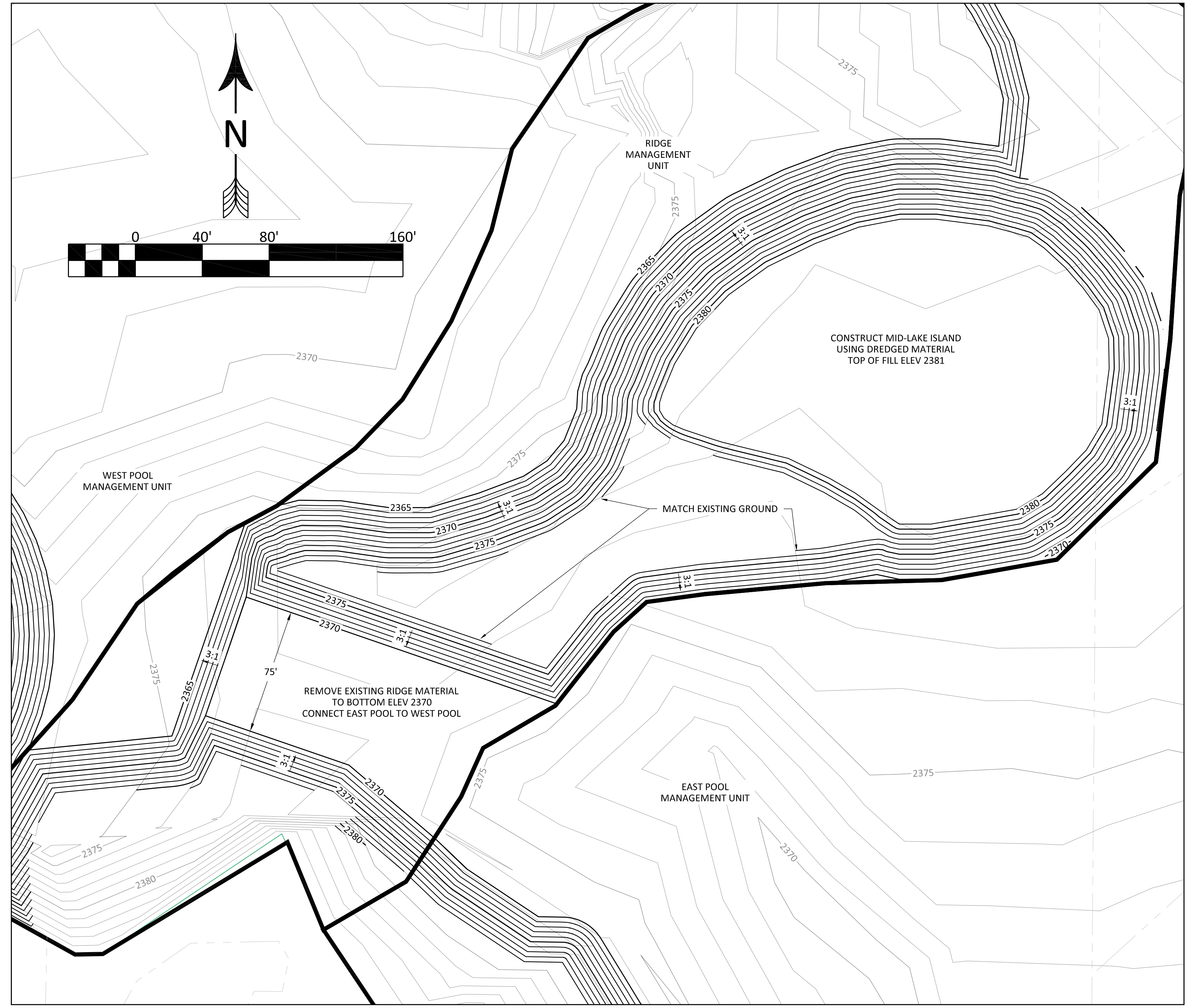

EAST/WEST POOL CONNECTOR CHANNEL AND MID-LAKE ISLAND GRADING

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PHOENIX LAKE PRESERVATION AND RESTORATION PLAN

POOL CONNECTORS AND ISLAND GRADING PLAN

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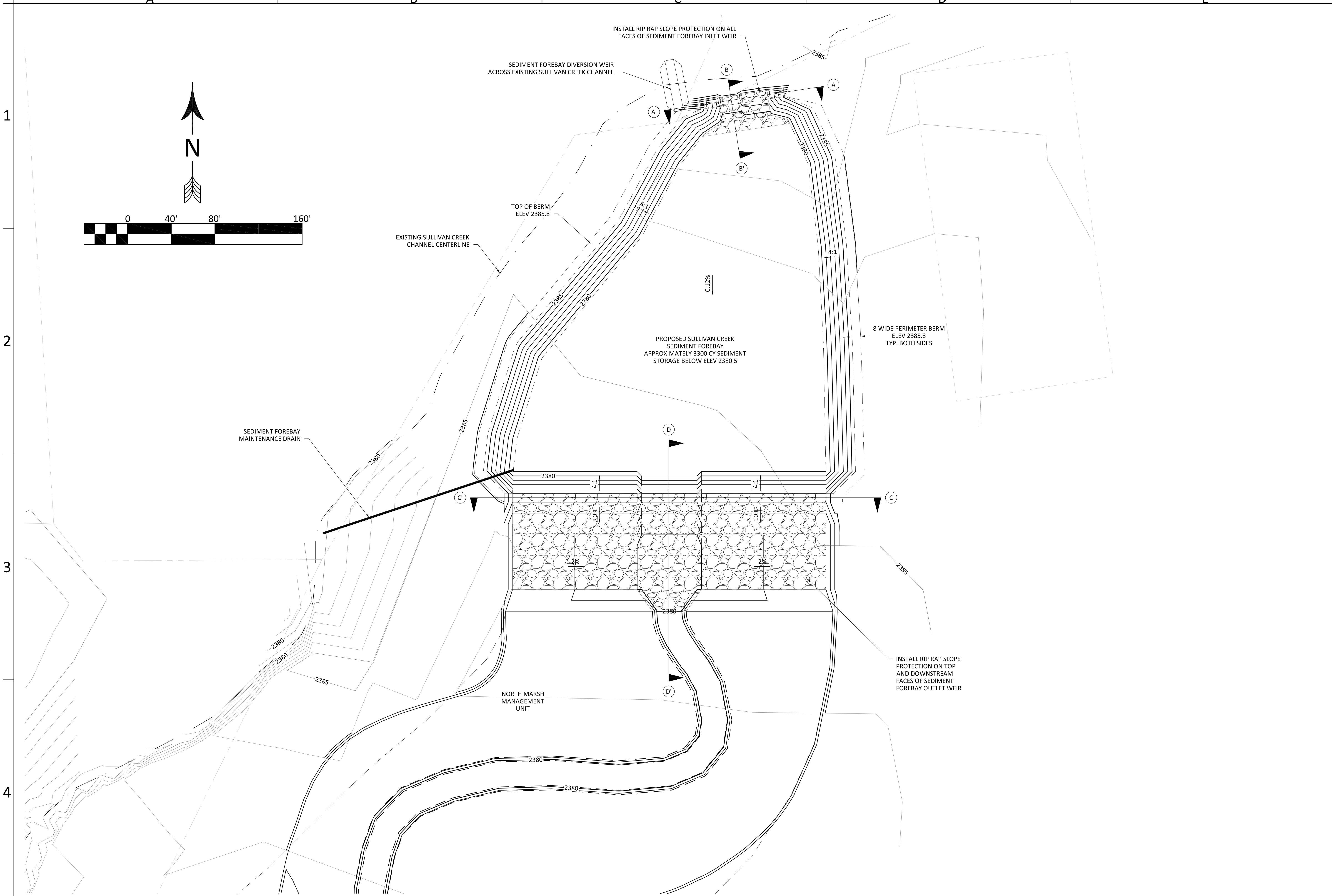
JOB NUMBER 10-1019
DATE February, 2012
SHEET NO. 8 OF 13



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SULLIVAN CREEK SEDIMENT FOREBAY GRADING PLAN

FILE NAME
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9 OF 13

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REALIGNED SULLIVAN CREEK GRADING PLAN

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DATE
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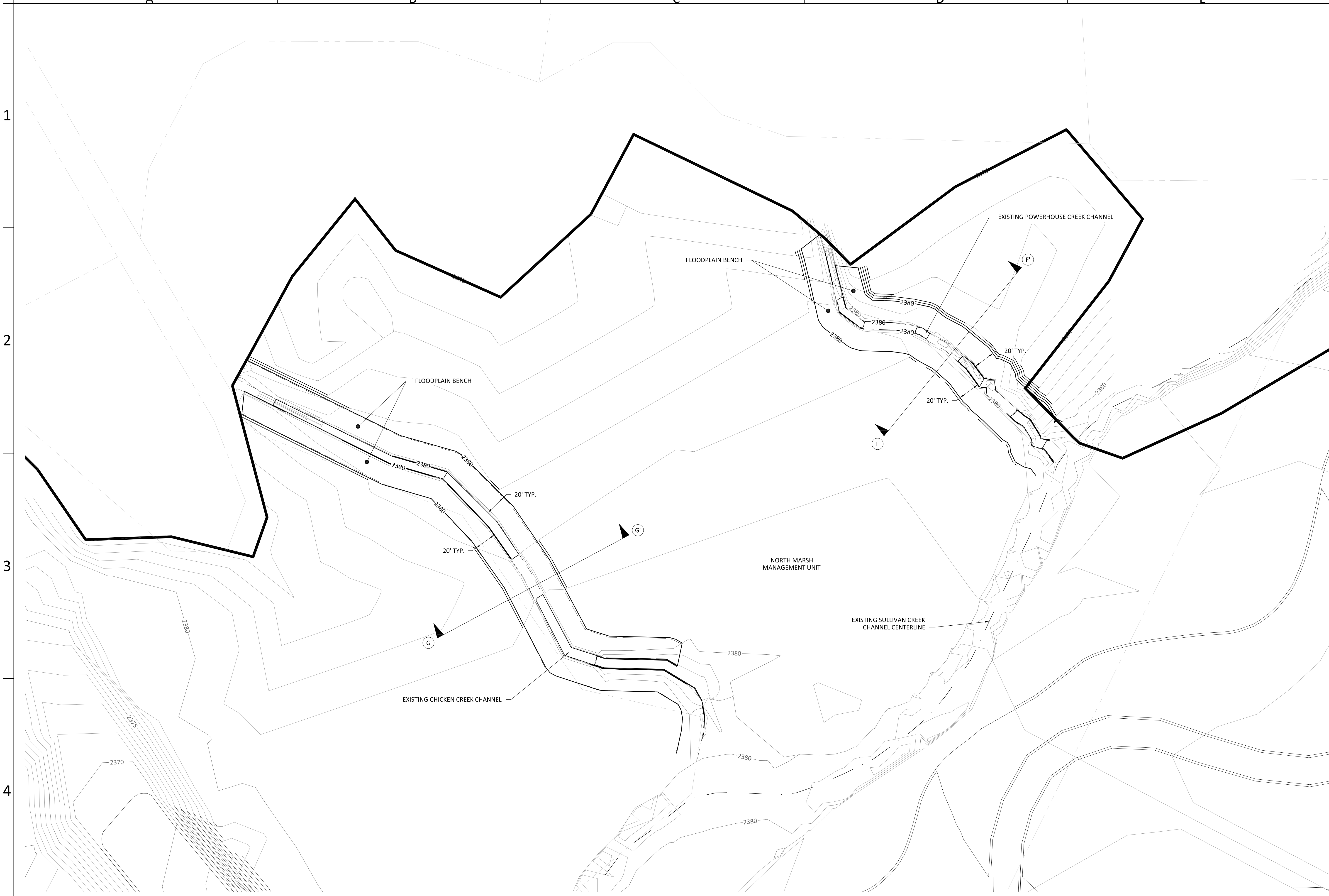
10 OF 13



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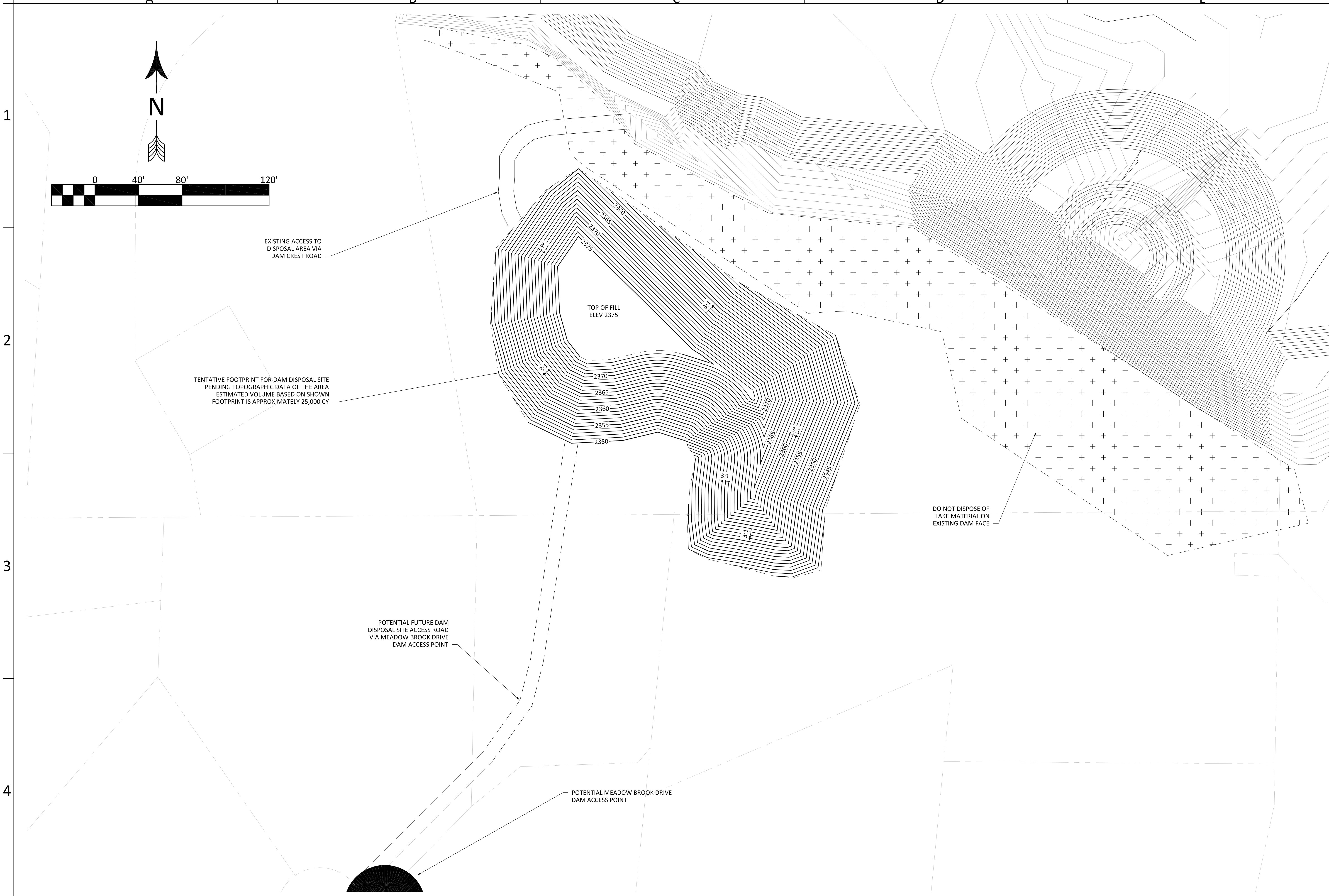
PHOENIX LAKE PRESERVATION AND RESTORATION PLAN

POWERHOUSE AND CHICKEN CREEKS GRADING PLAN

FILE NAME PowerChicken.dwg
JOB NUMBER 10-1019
DATE February, 2012
SHEET NO. 11 OF 13



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PHOENIX LAKE PRESERVATION AND RESTORATION PLAN
DAM DISPOSAL SITE GRADING PLAN

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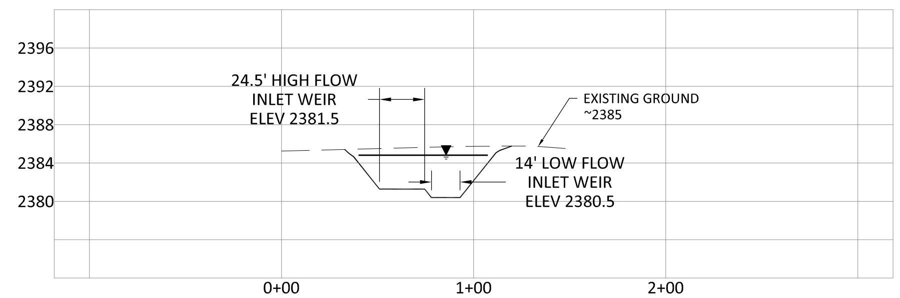
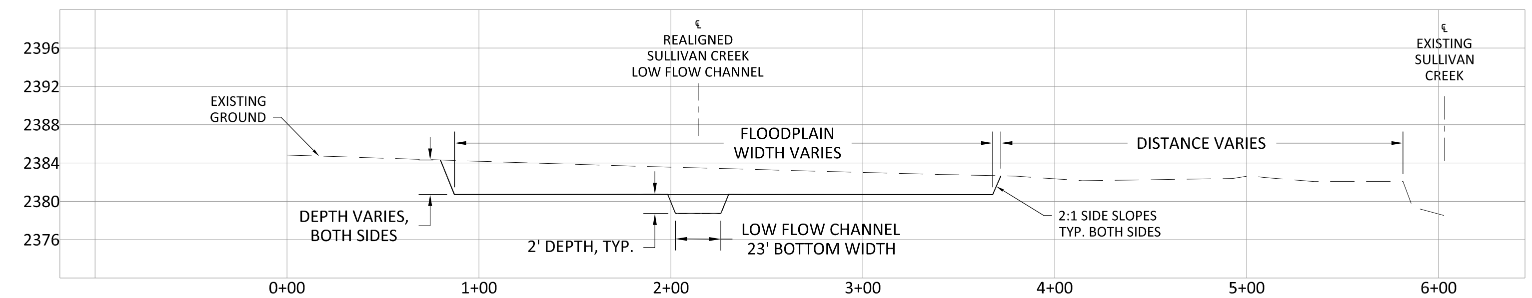
JOB NUMBER
10-1019
DATE
February, 2012
SHEET NO.
12 OF 13



SECTION A-A' - PROPOSED SEDIMENT FOREBAY INLET WEIR CROSS SECTION



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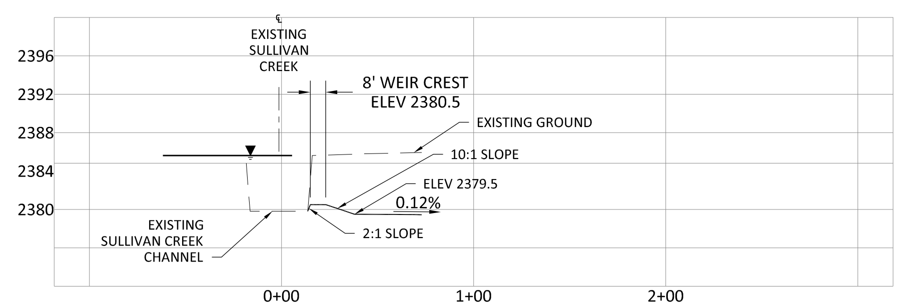

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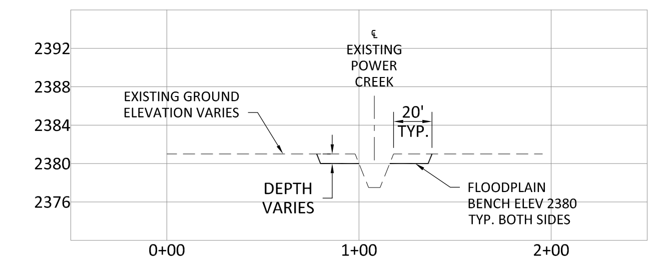
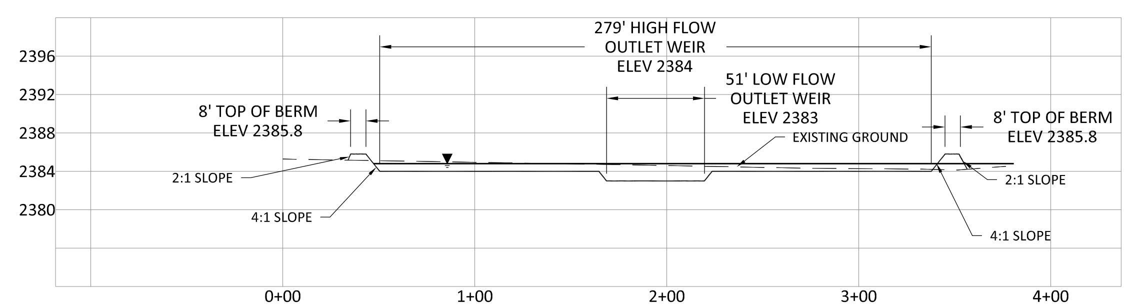


SECTION F-F' - POWER CREEK FLOODPLAIN BENCHES



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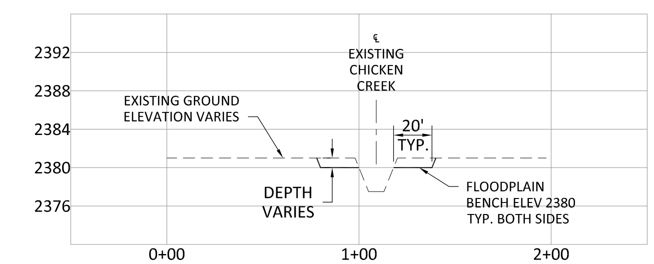
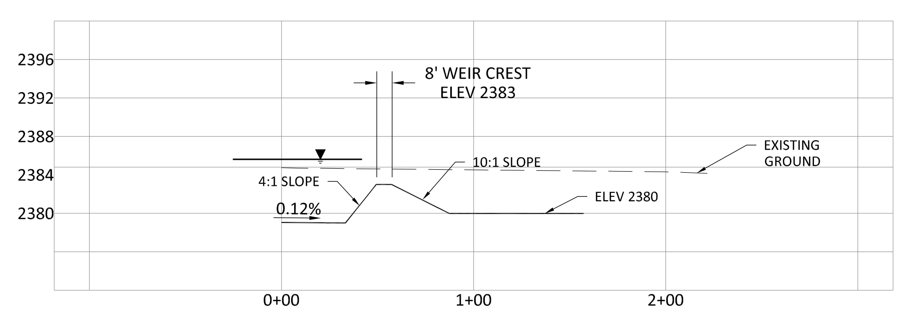
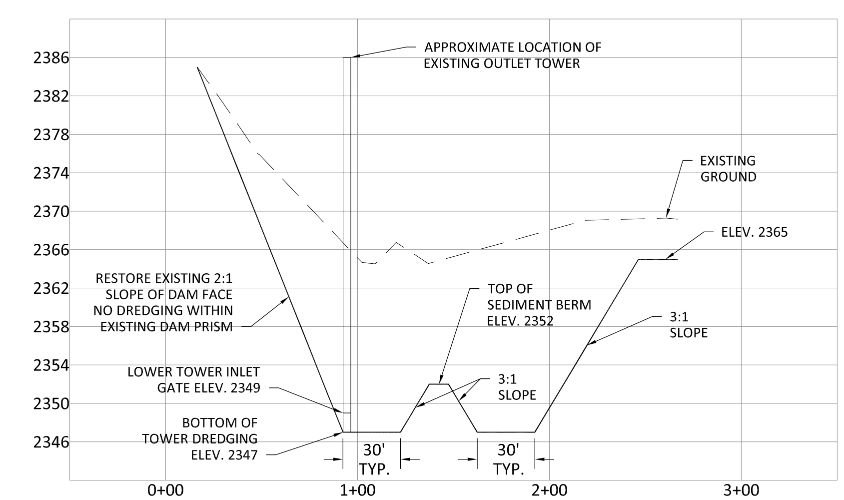


SECTION G-G' - CHICKEN CREEK FLOODPLAIN BENCHES



SECTION D-D' - PROPOSED SEDIMENT FOREBAY OUTLET LOW FLOW WEIR PROFILE



SECTION H-H' - TOWER INLET GRADING

SCALE

HORIZONTAL	1" = 50'
VERTICAL	1" = 5'

THIS LINE IS ONE INCH LONG WHEN THIS DOCUMENT IS PRINTED FULL SIZE

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PROPOSED GRADING CROSS SECTIONS

FILE NAME Grading_XS.dwg
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APPENDIX 3-C -2

TUOLUMNE UTILITIES DISTRICT

Phoenix Lake Preservation and Restoration Plan – Chapter 4 - Water Quality Monitoring & Improvement Plan

1.0 INTRODUCTION

This Water Quality Improvement Plan (WQIP) has been developed for the Tuolumne Utilities District (TUD) as part of the Phoenix Lake Preservation and Restoration Plan (PLPRP). The purpose of the WQIP is to: (1) summarize water quality conditions in Phoenix Lake based on water quality sampling conducted in the fall of 2010 and the spring/summer of 2011; (2) identify the potential factors that influence water quality in the lake; (3) outline management actions to potentially improve water quality; and (4) provide guidelines for long-term water quality monitoring. This chapter is organized as follows:

2.0 WATER QUALITY SAMPLING & ANALYSES

2.1 Methods

Between November 2010 and October 2011, direct measurements of water quality parameters were collected in and around Phoenix Lake. The purpose of these sampling efforts was to characterize water quality in the lake, an effort that has not been conducted in the past. The monitoring program aimed to characterize water quality condition in the context of the designated beneficial uses of the Upper Tuolumne watershed as established by the Central Valley Regional Water Quality Control Board (RWQCB, 2009). The beneficial uses that apply to Phoenix Lake include water supply, non-water contact recreation (e.g., boating), and wildlife habitat. The monitoring program also considered factors that contribute to lake aesthetics (e.g., extent of aquatic vegetation, water clarity).

Discrete measurements of general water chemistry, bacteria, and nutrients were taken on February 3, August 3, and September 20, 2011. Methodologies for the sampling program are detailed in Appendix A of this chapter. Figure 1 shows the water quality sampling sites. Due to changing conditions within the lake, such as limited access to shallow areas during the winter when the lake water level is low, the sampling locations and some parameters were modified from what was described in Appendix A. For example, in February 2011 sampling site PL-4 was unreachable by boat; samples were taken at site PL-4+, as shown in Figure 1. Water quality parameters analyzed at each station are shown in Table 4-1. In addition to the discrete measurements, water temperature was recorded semi-continuously (1-hour intervals) from November 2010 to October 2011 at station PL-1. All collected have been provided to TUD in electronic format.

Notes: Base map courtesy of Bing Maps

Horizon WATER and ENVIRONMENT

Phoenix Lake Preservation & Restoration Plan

Water Quality Sampling Sites

July 2012

Created By: KF

Figure 4-1

Table 4-1. Water Quality Sampling Activities by Station							
Water Quality Parameter	**Intake Tower (Station PL-1)**	**North Lake (Station PL-2)**	**Lake Outlet (Station PL-3)**	**South Lake (Station PL-4)**	**Boot Area (Station PL-5)**	**Sullivan Creek (Station SC-1)**	**Chicken Creek (Station CC-1)**
Temperature	Semi-Continuous	Discrete	Discrete	Discrete	Discrete	Discrete	Discrete
pH and turbidity	X	X	X	X	X	X	X
Depth	X	X	X	X	X		
Dissolved Oxygen profiles	X	X	X	X	X	Discrete	Discrete
Lab analysis of bacteria and nutrients	X		X	X		X	X

2.2 Results and Discussion

Discrete Dissolved Oxygen and Temperature Profiles

Depth-integrated profiles of dissolved oxygen and other water quality parameters were recorded to determine the level of stratification in the lake. When a lake is stratified, three temperature layers are formed; the *epilimnion* – the warmest, less dense upper layer; the *hypolimnion* – the coolest, less dense lower layer; and a layer in between where the temperature rapidly changes – the *thermocline*[1]. The exact boundaries are not always easy to detect and the layers are dynamic and fluctuate seasonally (Horne and Goldman, 1994). The layers of a stratified lake can mix or “turn over” seasonally. When this occurs, nutrients held in cold bottom lake layers are released to the surface layers. Figure 4-2 is an exaggerated example compared to Phoenix Lake, but illustrates a general representation of temperature profiles in a deep, stratified lake.

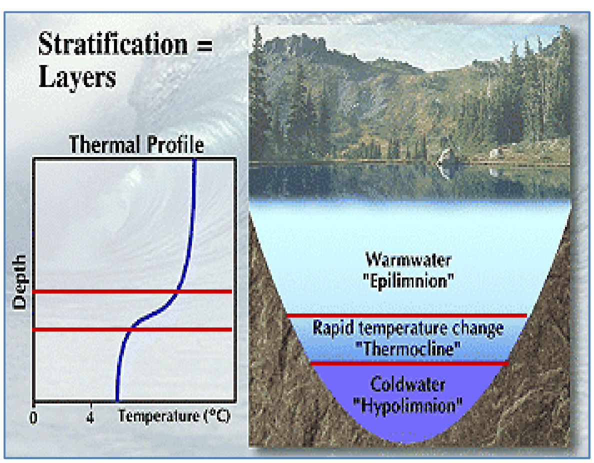


Figure 4-2: Typical Lake Stratification Layers.
(University of Guelph, 2011)

Dissolved oxygen in the water column generally tracks water temperature and light penetration. It is lowest at deeper depths where less light penetrates and the water is colder, and increases nearer to the water surface where atmospheric exchange influences oxygen concentrations. This effect is illustrated in Figure 4-3 which depicts dramatic temperature and dissolved oxygen profiles with a distinct thermocline.

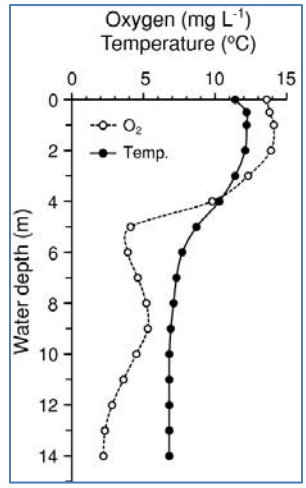
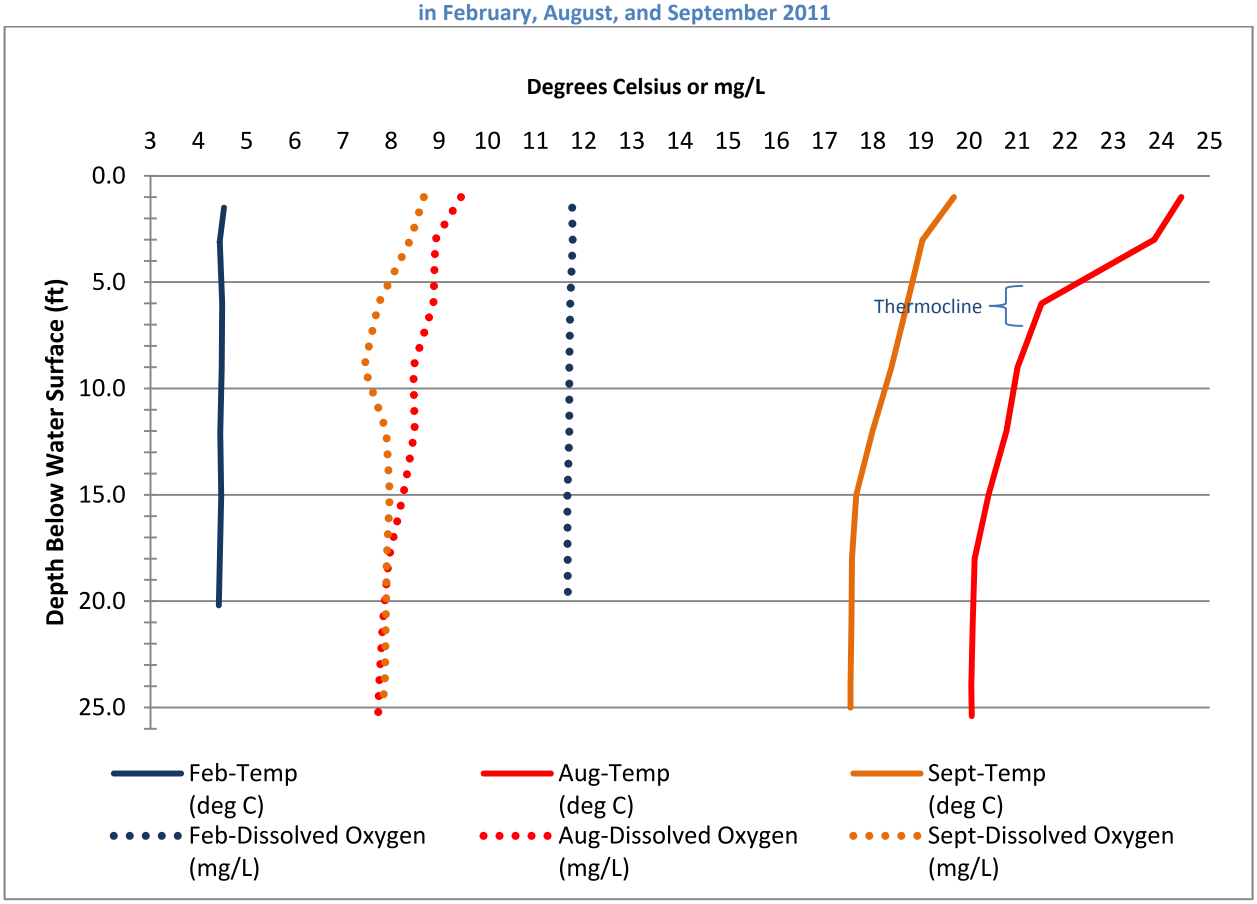


Figure 4-3: Example Temperature and Dissolved Oxygen Profile for a Deep Lake

Phoenix Lake is shallower than the lake depicted in Figure 4-3 (~ 9 m versus 14 m), and thus depth profiles for temperature and dissolved oxygen are not as dramatic as those shown in Figure 4-3. However, shallow lakes can still stratify and the data recorded at the deepest part of Phoenix Lake (at the intake tower) in different seasons indicate that the lake is mildly stratified in the summer, with the thermocline located approximately 3 to 5 feet below the surface. During the winter, the lake is well mixed with no thermocline formation. Figure 4-4 illustrates temperature and dissolved oxygen depth profiles from data recorded in February (winter season), August (summer), and September (early fall) of 2011. The approximate depth of the thermocline during the summer of 2011 is indicated in Figure 4-4.

[1] Put another way, the thermocline is the region in the lake with the greatest inflection in the temperature-depth curve.

Figure 4-4: Depth Profiles for Temperature and Dissolved Oxygen at Intake Tower (PL-1) in February, August, and September 2011



Monitoring of diurnal fluctuations in temperature and dissolved oxygen is another method to investigate lake conditions. Large daily variations in temperature and dissolved oxygen concentrations can occur during summer months, especially in eutrophic systems. If a sufficient nutrient supply is present during the summer when temperatures are warmest, photosynthesis activity of submerged aquatic plants can deplete dissolved oxygen in the water column, leading to formation of anoxic (lacking oxygen) conditions which can threaten aquatic life. Further discussion on the influence of aquatic plants and photosynthesis on lake water quality is provided in Section 3.

To evaluate this effect in Phoenix Lake, depth profiles for temperature and dissolved oxygen were recorded early in the morning when photosynthesis activity is lowest, and throughout the peak of the day when photosynthesis activity peaks. In August and September 2011, temperature and dissolved oxygen profiles were recorded at 3-foot depth intervals from four locations around the lake. Depth profiles were recorded at approximately 6 a.m., 7:45 a.m., 930 a.m., 11 a.m., and 1 p.m. in August, and at approximately 11 a.m., 1:30 p.m., and 3 p.m. in September.

The data recorded in August and September 2011 indicate that water temperature and dissolved oxygen do not vary much throughout the day. In August, water temperature varied by one degree at each of the times sampled between 6 a.m. and 1 p.m. In September, temperatures overall were lower than in August and the temperature was highest at 3 p.m., though the temperature only varied by one degree between 11 a.m. and 3 p.m. Dissolved oxygen values recorded at different times were consistent throughout the day at all locations sampled; there were no significant changes in dissolved oxygen concentrations recorded early in the morning or late in the afternoon.

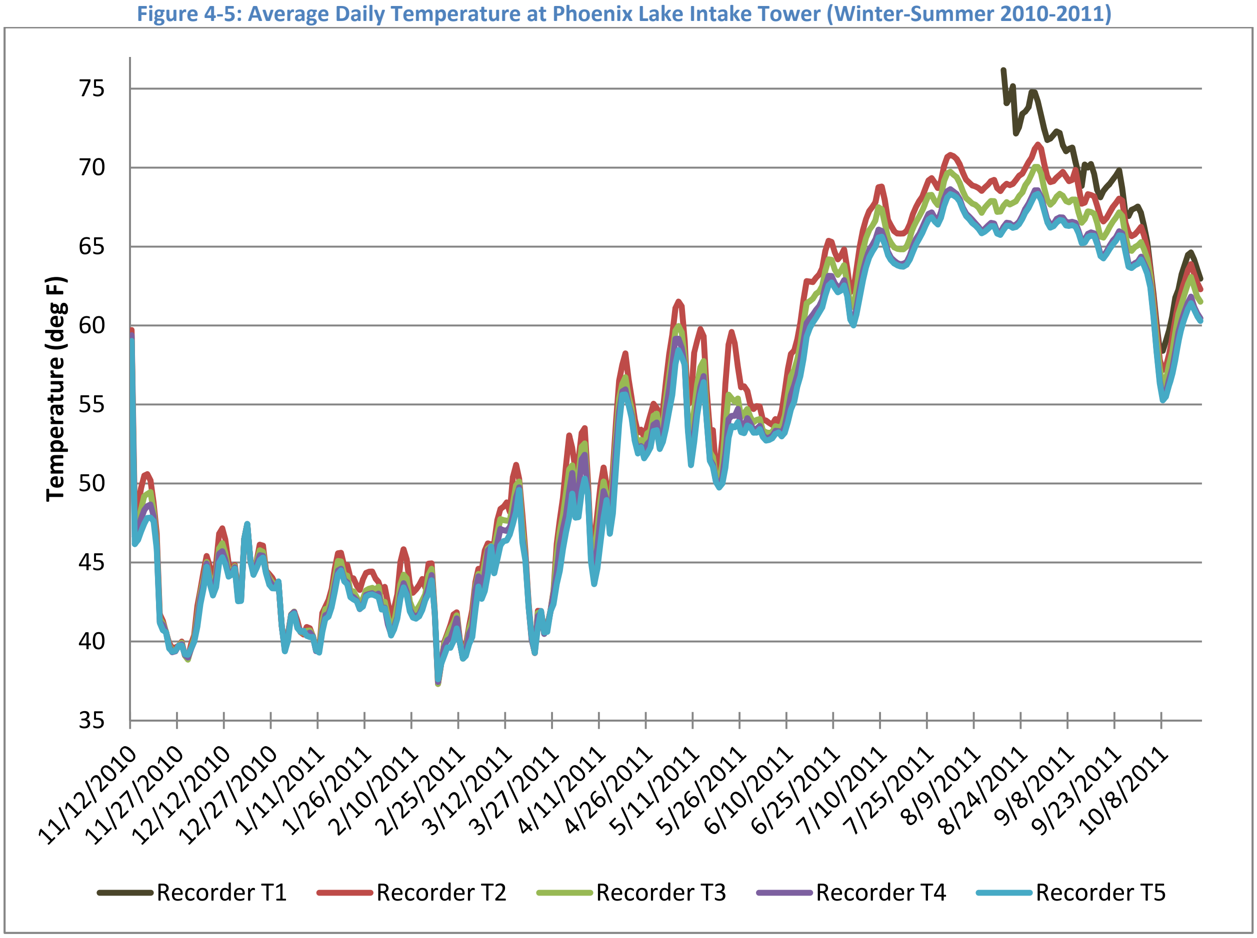
August was the annual peak in water temperatures and when the lake was the most stratified. Water temperatures in August were highest at 1 p.m., reaching 25 deg C (77 deg F) at the surface and 20 deg C (68 deg F) at the lake bottom, 25 feet below the surface (Figure 4-4). The daily fluctuations in dissolved oxygen concentrations were not as wide as anticipated. However, the data do show a 20% decrease in concentrations between the surface and lake bottom. Dissolved oxygen concentrations consistently ranged from 100% saturated (8-9 mg/L) or greater in the upper 3 feet of the water column, and 80% saturated (7 mg/L) in the lowermost depths around the lake. These concentrations are well within the range to support aquatic life and are not indicative of degraded water quality.

Semi-continuous Water Temperature Monitoring

Water temperature data were collected semi-continuously (1-hour intervals) using HOBO® Pro v2 temperature data loggers. Four data loggers were installed in November 2010 at the TUD intake tower (station PL-1) at depths shown in Table 4-2. In August 2010, an additional data logger was installed near the lake surface to account for the rise in water surface elevation due to installation of the flashboards. The data loggers were placed at fixed elevations; because the lake level fluctuates seasonally, the depth at which the data loggers recorded data varied accordingly. Average daily temperatures recorded at the intake tower are plotted in Figure 4-5. The temperatures plotted in Figure 4-5 include the data from each of the five recorders listed in Table 4-2.

Table 4-2. Water Temperature Instrumentation Depths		
Instrument ID	Depth below surface at Ordinary Winter Lake Level (ft)	Depth below surface at Ordinary Summer Lake Level (ft)
T1	NA	2
T2	2	8
T3	8	14
T4	12	18
T5	18	24

Figure 4-5: Average Daily Temperature at Phoenix Lake Intake Tower (Winter-Summer 2010-2011)



This plot illustrates the range of water temperatures experienced over the sampling period. Because the lake is generally shallow (less than 25-30 feet deep), temperatures generally track the seasonal air temperatures. Temperatures remained cooler (between 40 and 50 degrees) between November and March, and rose to 65 and 70 degrees between July and September. As expected, temperature recorders placed at deeper depths reflect cooler temperatures compared to those nearer to the surface. This effect is the most distinct in the summer months (July to early September) when the lake is slightly stratified.

Coliform Bacteria

Results from coliform bacteria sampling are shown below in Table 4-3. The lab analysis conducted were the standard tests for total and fecal coliform and E. coli, which indicate the presence of human or animal waste (see Table A-1 in Appendix A for the analysis protocols). These tests do not provide information on the source of the bacteria.

Coliform bacteria were documented during all sampling events at all stations. Total coliform counts were greatest during the dry season in Sullivan Creek. When streamflow is low in the summer a larger percentage of the flow may be associated with nuisance water discharges (e.g., overwatered landscaping, car washing runoff, leaky septic systems), rather than natural runoff. In the winter time, flows are diluted by natural runoff. This likely explains the elevated counts of bacteria in Sullivan Creek in the summer. Chicken Creek was not sampled in the summer because the station was dry, but this creek also showed elevated levels of coliform in the February sampling event. This is potentially attributed to discharges from agricultural operations upstream of the sampling site. However, the limited sampling performed during this study cannot attribute coliform loads to a specific source. In the lake, coliform counts were generally highest in the winter, with lower levels documented in the summer. This is somewhat surprising given the high bacterial loads entering the lake from Sullivan Creek in the summer, and that bacteria are more productive in the summer months. It is possible that the samples from the winter detected bacteria from avian (bird) sources. Avian activity is greater in the winter than in the summer months.

Photo 4-1: Water sample collection in Phoenix Lake (September 20, 2011)

Other Parameters

Table 4-3 includes the results of other water quality characteristics analyzed on the three sampling events in 2011 (February, August, and September). Chemical parameters analyzed included chlorides, total dissolved solids, total suspended solids, various forms of nitrogen, and various forms of phosphorus (See Table A-1 in Appendix A for the analysis protocols). These samples were taken from the lake surface (approximately 1 ft below the surface) and from Sullivan and Chicken creeks. Overall, the results did not detect high levels of these constituents. Nitrate was consistently detected at Sullivan Creek, but at low levels (the U.S. EPA drinking water threshold is 10mg/L and the concentrations detected were less than 1.5 mg/L for all samples).

Turbidity measurements were also obtained at each of the monitoring sites. The data collected in February with a Hach© turbidimeter showed lake turbidity at 4-5 NTU in various locations. A water quality monitoring multi-probe YSI© sampling device with a built-in turbidimeter was used for the August and September sampling events. All the data collected during the August sampling were not considered valid (readings were below zero NTU, which does not make sense). Data recorded during the September sampling event showed turbidity levels ranging from 0-6 NTU at about three-quarters of the lake monitoring sites, the remainder of the readings were below zero like in August. It is assumed that the multi-probe sampling device was not calibrated to detect the turbidity levels exhibited in Phoenix Lake. Future efforts to detect turbidity should include appropriate calibration of the sampling equipment.

Table 4-3: Phoenix Lake Chemistry Test Results (February, August, September 2011)

Sample Location	Sample Date 2011	Chloride (mg/L)	Total Dissolved Solids (mg/L)	Total Suspended Solids (mg/L)	Nitrogen: Nitrate as N (mg/L)	Nitrogen: Nitrite as N (mg/L)	Nitrogen: Ammonia as N (mg/L)	Nitrogen: Total Kjeldahl Nitrogen (mg/L)	Nitrogen: Total Nitrogen (mg/L)	Phosphorus: Orthophosphate as PO4 (mg/L)	Phosphorus: Phosphorus (mg/L)
Sullivan Creek at Potato Ranch Road	Feb 3	7.5	83	ND	0.5	ND	Not tested	ND	ND	ND	ND
	Aug 3	5.9	97	ND	0.34	ND	Not tested	ND	ND	ND	ND
	Sept 20	6.6	110	ND	0.49	ND	0.18	ND	ND	ND	ND
Chicken Creek at Mouth near Apple Valley Estates	Feb 3	28	170	ND	1.3	ND	Not tested	ND	1.3	ND	0.15
	Aug 3	Creek dry									
	Sept 20	Creek dry									
Lake Intake Tower (PL-1)	Feb 3	4.6	67	ND	ND	ND	Not tested	ND	ND	ND	ND
	Aug 3	2.7	27	ND	ND	ND	Not tested	ND	ND	ND	ND
	Sept 20	1.3	27	ND	ND	ND	ND	ND	ND	ND	ND
Lake Outlet (PL-3)	Feb 3	4.9	70	5.0	0.23	ND	Not tested	ND	ND	ND	ND
	Aug 3	2.1	32	ND	ND	ND	Not tested	ND	ND	0.64	ND
	Sept 20	1.9	25	ND	ND	ND	0.19	ND	ND	ND	ND
Mid-Lake (PL-4)	Feb 3	4.8	71	ND	0.23	ND	Not tested	ND	ND	ND	ND
	Aug 3	2.5	32	ND	ND	ND	Not tested	ND	ND	ND	ND
	Sept 20	2.2	32	ND	ND	ND	ND	ND	ND	ND	ND

Notes:
USEPA Primary and Secondary Drinking Water Regulations (2009) are:
Chloride – 250 mg/L
Nitrate as N – 10 mg/L
Nitrite as N – 1 mg/L
Total Dissolved Solids – 500 mg/L
(Drinking water standards have not been established for the other parameters shown in this table.)
Ammonia was analyzed in the September samples only due to an oversight on laboratory testing procedures.

3.0 FACTORS INFLUENCING WATER QUALITY IN PHOENIX LAKE

Lakes are typically classified by their trophic state. A *eutrophic* lake has warm water, high nutrient levels, abundant plant growth and algal blooms. Clear Lake, in Lake County, California is a good example of a eutrophic lake. An *oligotrophic* lake has cold water, low nutrients levels and limited plant growth. Lake Tahoe is a good example of an oligotrophic lake; more precisely it is classified as an ultra- oligotrophic lake because nutrient concentrations are very low. Phoenix Lake falls in between these two trophic categories and can be classified as a *mesotrophic* lake. While much of Phoenix Lake has abundant plant growth, the lake does not have high nutrient concentrations or low dissolved oxygen concentration, which are characteristics of a eutrophic lake. Algal blooms do occur in warmer summers, especially if preceded by a warm, dry spring. These are the years when local residents complain about the taste of treated water.

In general, under natural conditions a lake will progress from a low nutrient state to a eutrophic condition, a process referred to as *eutrophication*[2]. The rate at which this occurs is a function of the nutrient and sediment supply, climate and the dimensions of the lake (depth and area). Because nutrient and sediment supply influence the rate of eutrophication, a lake is sensitive to land use changes in the watershed. Phoenix Lake has been heavily influenced by influxes of sediment (See Chapter 2 of the PLPRP). In addition to sedimentation, land use activities that contribute nutrients to lake (e.g., runoff from golf courses; leaky septic systems; agricultural operations; avian populations) will accelerate the rate of eutrophication. This section continues with a discussion of the factors that influence water quality and the eutrophication rate in Phoenix Lake.

Effects of Aquatic Vegetation on Water Quality

Land use and natural environmental discharges to a shallow, warm-water lake heavily influence water quality, particularly related to inputs of sediment, nutrients, and bacteria. Nutrient discharges encourage growth of aquatic vegetation such as the invasive, non-native Eurasian watermilfoil (*Myriophyllum spicatum*, Photo 4-2).

Photo 4-2: Eurasian watermilfoil mats in Phoenix Lake

Aquatic vegetation stores energy and nutrients in its roots during the winter and grows rapidly in the spring, forming thick dense mats in the lake. The lifecycle of aquatic vegetation influences water quality in a lake. As light availability and temperatures rise throughout the day, the photosynthetic activity in plants increases and oxygen is released to the upper water column. At the highest peak of temperatures in the day, oxygen levels near the lake surface become supersaturated (beyond 100% saturated). In this condition, aquatic vertebrates like fish avoid the area. As the season gets cooler and aquatic vegetation dies off, dead vegetative matter sinks to the lake bottom. The decomposition process at the lake bottom uses available oxygen in the water

[2] Eutrophication is the process of increased productivity of a lake as it ages.

column, thus oxygen concentrations in lower layers of a eutrophic lake are significantly lower, sometimes to the point where there is not enough oxygen for aquatic vertebrates to survive. Similarly, high concentrations of nitrogen-fixing bacteria can also influence dissolved oxygen conditions. With warm, supersaturated oxygen conditions at the surface, and cool oxygen depleted conditions at the bottom, the most suitable area for fish is in the mid-lake layers. These conditions, as exhibited in a eutrophic lake, are illustrated in Figures 4-6 and 4-7.

While Phoenix Lake is generally low in nutrient content (based on the limited sampling efforts conducted), the fact that the lake is shallow and relatively warm creates preferable conditions for widespread growth of Eurasian watermilfoil. During the summer, thick mats of these plants cover nearly the entire lake, especially on the east side of the lake where depths are the shallowest. The photosynthesis cycling conditions described above and depicted in Figures 4-6 and 4-7 were slightly detected in the water quality sampling conducted during 2011. While Phoenix Lake does not currently exhibit anoxic (very low oxygen) conditions at the lake bottom, ongoing sedimentation and proliferation of aquatic vegetation will eventually lead to eutrophic conditions in the lake.

Creek Discharges

Sediment loading from creeks significantly influences the lake's turbidity and as sediment accumulates in the lake, the water column depth is reduced. Reduced depth results in increased mean summer water temperatures and expansion of suitable habitat for aquatic vegetation. This increases the eutrophication rate of the lake. Additionally, agricultural operations, golf courses and residences within the watershed may contribute nutrients to stormwater runoff through the use of fertilizers, leaky septic systems, and livestock (Photo 4-3) and domestic animal waste.

Photo 4-3. Livestock are a potential source of nutrients and bacteria to the lake (Sullivan Creek watershed, February 2011.)

Nitrate concentrations (at low levels) were consistently detected in samples from Sullivan Creek. However, chronic nutrient loading does not appear to be a problem based on the limited sampling conducted. Pulses of nutrients from agricultural activities in the watershed delivered during storm events may be more problematic.

Avian Populations

As indicated by the sample results shown in Table 4-3, there are high concentrations of bacteria present both in the lake and two of the major tributaries (i.e., Sullivan and Chicken creeks). Large flocks of avian populations are attracted to the lake (birds like to eat aquatic vegetation) and potentially to the Phoenix Lake Golf Course as well (geese are common resident of golf courses). Resident geese populations may contribute a significant amount of bacteria to the lake.

4.0 FUTURE MANAGEMENT & MONITORING ACTIONS

4.1 Management Actions

Future management actions for the lake and watershed are described in Chapters 3 and 4 of the PLPRP. Management actions include removing accumulated sediment from the lake bottom, harvesting or otherwise controlling aquatic vegetation, and initiating sediment source controls throughout the watershed to reduce sediment delivery to the lake. After the lake has been dredged and sediment management practices are in place, water clarity should improve. During the lake dredging process, a high percentage of the existing invasive aquatic vegetation (primarily Eurasian watermilfoil) will be removed along with the sediment. However, the invasive plants cannot be completely removed, as Eurasian watermilfoil is a regenerative species, which can reproduce from a single stem fragment of plant material. As such, Eurasian watermilfoil will likely persist in the lake, though to a lesser extent and density after the lake is dredged because growth will be limited by water depth. Regular maintenance of aquatic vegetation following sediment removal, or as an interim lake management measure (See Part I of Chapter 3), would help maintain or improve water quality and lake aesthetics.

Compared to existing conditions, the water quality characteristics of the lake after dredging will likely reflect modest changes in temperature, dissolved oxygen, nutrients, and other standard constituents. At present, Phoenix Lake is in a mesotrophic state, but is trending to a eutrophic condition. Sediment removal in the lake will reset conditions, and along with sediment management practices, will slow the rate of eutrophication. Control of human-derived nutrient sources in the watershed would also slow the rate of eutrophication and extend the life of the lake. With respect to elevated levels of bacteria detected in and around the lake, further investigation is needed to identify the source of the high concentrations and options to address them.

Water Supply & Treatment

The most significant issues for treatment of Phoenix Lake for drinking water are seasonally high turbidity and organics concentrations which results in taste and odor issues (Pers. comm., Lemaster 2011). High turbidity and organics in the lake source water peaks during winter storm events. The turbidity levels stabilize within a few hours to a few days depending on the severity and duration of the storm event. Both the Sonora and Scenic View water treatment plants are designed to treat the source water with chemicals to produce “floc” particles (i.e., conglomerated particulates of sediment and organic material suspended within the water column). The floc particles are filtered out of the water column, and the treated water is next passed through granular activated carbon filters to remove remaining particulates and improve the water’s taste and odor. The TUD’s treatment plants function properly over 80% of the time (Pers. comm., Lemaster 2011). It is only during the winter storm season that the plants have difficulty treating the water. The plants are designed to produce floc, thus the more particulates of sediment and organics in the water column, the better; high concentrations of organic matter and turbid water are actually easier to treat compared to the “cleaner” less turbid water. For the Scenic View treatment plant, the biggest issue is the small size of the plant rather than water quality. The small Scenic View plant cannot quickly adjust to large pulses of highly turbid water during winter storms.

Sediment reductions from watershed erosion control efforts (see Chapter 2), sediment management within the lake (see Chapter 3), and reduced organic material in the lake after dredging will improve the quality of the lake source water and help control taste and odor of the treated water, especially during the high runoff storm season when turbidity is at its highest. Complete removal of aquatic vegetation and suspended sediment in the water column may make water treatment more difficult. However, this is considered to be an unlikely scenario for Phoenix Lake.

4.2 Future Monitoring Actions

This report provides one year of monitoring data and is based on limited sampling. It would be beneficial to continue a water quality sampling program at Phoenix Lake to establish a more robust baseline dataset and enable the detection of trends in water quality conditions. Recommended future monitoring actions include:

A. Continue seasonal field measurements in and around the lake:
    - Collect spring and summer samples from in-lake and creek sampling stations (bacteria, nutrients, water chemistry)
    - Use a secchi disk to monitor lake clarity/turbidity.

B. Conduct sediment transport monitoring in the major tributaries. This would likely include direct sampling of sediment loads (bedload and suspended load), as well as installation of optical turbidity probes.

C. Conduct additional sampling in the watershed to identify sources of nutrients. Sampling locations should be established upstream and downstream of likely sources of nutrients such as agricultural operations and golf courses.

D. Develop a short- and long-term aquatic vegetation management plan to control the spread and abundance of invasive Eurasian milfoil.

E. Conduct more in-depth testing to determine the source of fecal coliform detected in the lake:
    - Testing for presence of *Enterococcus* is a cost effective first step in identifying dominant sources of fecal coliform bacteria. *Enterococcus* is a bacterium that is common in human intestines. The test is relatively inexpensive and is a good indicator of human sources such as leaking septic systems.
    - To further identify sources of fecal coliform, a microbial source tracking (MST) test can be performed. This tests looks for genetic markers in a specific group of bacteria that is common in digestive systems of warm blooded animals. Markers can be detected for many sources including human, cattle and deer (non-ruminants), and hogs (feral and livestock). If the test results show that the majority of the fecal coliform is from human sources, malfunctioning septic or sewer systems should be investigated in areas draining to the lake and its tributaries.
    - If test results show that humans (or cattle or hogs) are not the primary source of fecal coliform, it may be deduced that avian contributions are the biggest influence. In that case, a focused study of bird populations in the lake, and at the golf course (geese like to graze on golf course grass) is recommended to identify methods to manage the bird populations and reduce bacteria inputs to the lake.

5.0 SUMMARY AND CONCLUSIONS

Phoenix Lake exhibits mesotrophic conditions and is trending to a eutrophic state. The rate of eutrophication has been accelerated by sedimentation, and to a lesser extent, by nutrient discharges, which are most likely from anthropogenic sources.

Based on the limited sampling conducted, there is little evidence of chronic nutrient loads that are problematic for potable water supply, aquatic organisms or terrestrial wildlife. In general, the quality of lake water is not problematic for treatment at the District's plants; it is primarily during and shortly after large storm events that the treatment plants struggle to function properly. There may also be drinking water taste and odor issues in the late summer if the treatment plant's granular activated carbon filtration system is nearly exhausted. Pulses of sediment, bacteria, and nutrients during storm events are perhaps the most problematic issues for water quality in the lake.

Lake water quality conditions will improve with dredging and sediment management (See Chapter 3, Part II). This will slow the rate of eutrophication and extend the life of the lake, but due to its size and depth it is not possible to change the lake to an oligotrophic state (clear, cold-water lake). Additional efforts to improve water quality in the lake should focus on watershed management actions (e.g., erosion control). Continued monitoring of lake water quality will inform water treatment operations and the planning of watershed management actions.

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